GAUGING THE OPERATIONAL VALUE OF NAVAL INFRASTRUCTURE

The Case of Surface Combatant Manning

Presentation to

The Second Annual Navy Manpower, Personnel, and Training Research and Analysis Conference

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BACKGROUND

- **THE NAVY HAS RECENTLY BEGAN ASKING HARD QUESTIONS ABOUT NAVAL INFRASTRUCTURE**
  - **What is the Military Value of Infrastructure?**
  - **How to Gauge Effect of Investments in Infra-structure upon the Navy's Warfare Capability**
- **THESE QUESTIONS ARE DRIVEN BY A NUMBER OF DIFFERENT SPECIFIC CIRCUMSTANCES**
  - ***Military*: Perceived Imbalance Between Structure and Infrastructure**
  - ***Financial:* No Money to Buy Enough of Both**
  - ***Administrative*: The Navy's IWAR Process**
- **TO ANSWER, ONE NEEDS TO QUANTITATIVELY CONNECT STRUCTURE AND INFRASTRUCTURE**

THE UNDERLYING DIFFICULTY

- **WARFIGHTING AND SUPPORT COMMUNITIES ARE NOT MEANINGFULLY CONNECTED TO EACH OTHER**
  - **Warfighting Community Focuses on Platforms and Systems, and Assumes Infrastructure Will be There**
  - **Support Community Focuses on Management, and Assumes Infrastructure Will be Useful**
- **EVEN DEFINITION OF INFRASTRUCTURE CURRENTLY IN USE NO LONGER POINTS TO ITS MILITARY VALUE**
  - **Either Characterized by Features Irrelevant to Warfighting, Such As Its Relation to Land**
  - **Or Reduced to a Mere Listing of Activities that Attempts to Be Neither Prioritized Nor Complete**

THE GUIDING IDEA

- **INFRASTRUCTURE IS THE SET OF ACTIVITIES THAT PRODUCES A NATION'S MILITARY STRUCTURE**
  - ***Acquisition*: Procures a Structure that is Ready for Operational Employment**
  - ***Maintenance*: Ensures the Structure Remains So**
  - ***R&D*: Adjusts Structure to Changing World**
- **THEREFORE, EACH STRUCTURE COMPONENT, BE IT MAN OR EQUIPMENT, HAS DOUBLE CHARACTER**
  - **As *Instrument of War* It Contributes to Warfare**
  - **As *Product of Infrastructure* it Reflects Quality of Activities that Contributed to its Production**
- **THIS OPENS THE WAY TO CONNECTING WARFARE CAPABILITY WITH QUALITY OF INFRASTRUCTURE**

ANALYTIC APPROACH

- **IN TIME OF PEACE, WARFARE CAPABILITY IS OFTEN ESTIMATED BY APPROPRIATE WARFARE MODELS**
  - **They Relate Warfare Capability to Inputs of Systems Performance and Human Proficiency**
  - **These Inputs are Numbers Usually Taken Either from Engineering Studies or from Fleet Data**
- **BUT, ALL INPUTS SHOULD BE FUNCTIONS OF INFRA-STRUCTURE ACTIVITIES INVOLVED, NOT NUMBERS**
- **THEREFORE, WE MUST RELATE ALL MODEL INPUTS TO THEIR RELEVANT INFRASTRUCTURE ACTIVITIES**
  - ***Performance Inputs*: R&D, Production, Repair**
  - ***Proficiency Inputs*: Recruitment, QOL, Training**

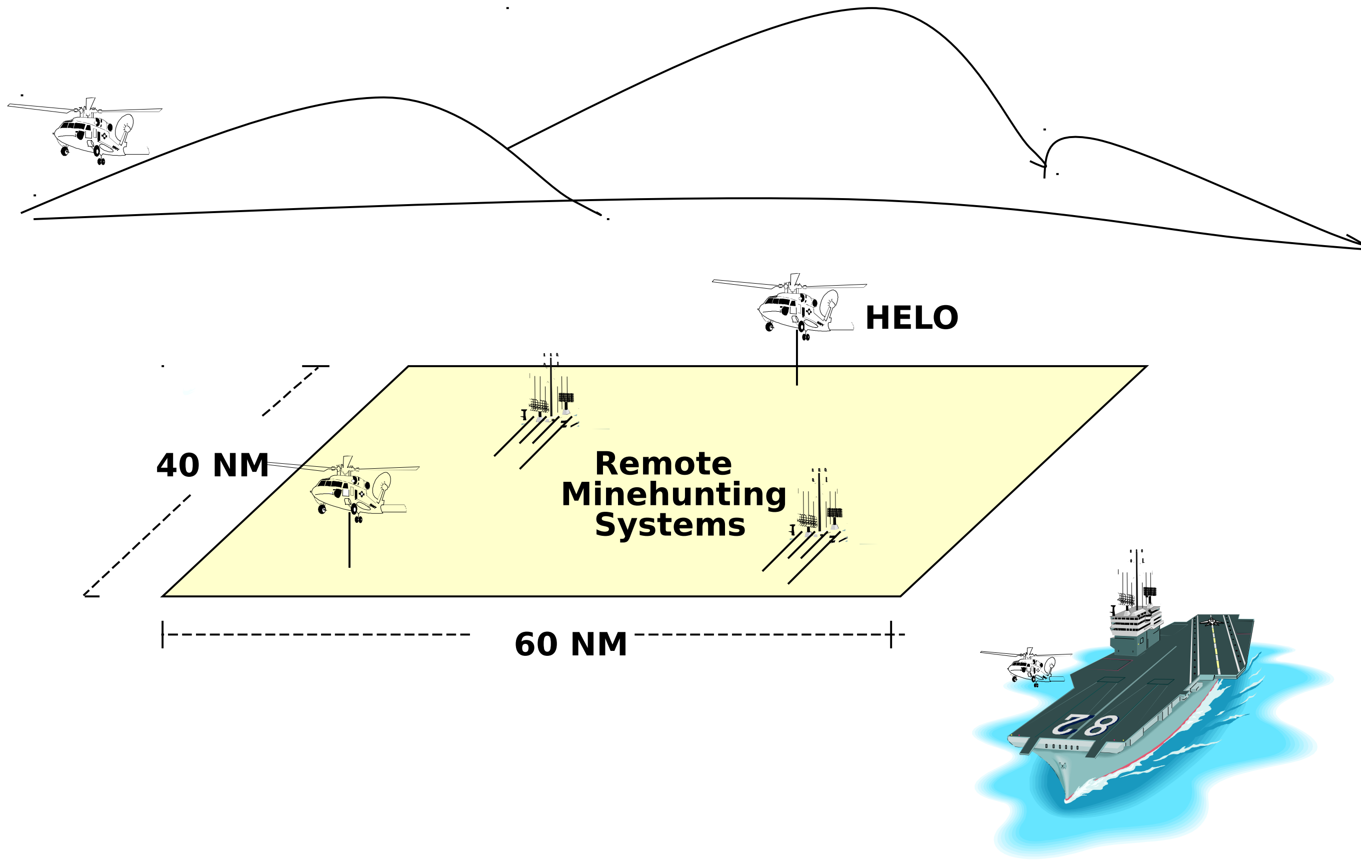
TESTING THE APPROACH

- **THE APPROACH CAN BE IMPLEMENTED**
  - **We Show that Approach can Relate Mission Effectiveness to Infrastructure Activities**
  - **Illustration: Organic Mine Countermeasures in Preparation for CV Operations**
  - **Illustration: Manning of Surface Combatants**
- **THE APPROACH CAN AID DECISION MAKERS**
  - **We Show that Approach Offers a Means of Trading Between Investments in Structure an Investments in Infrastructure Activities**
  - **Illustration: Should the Navy Build a Shallow Water ASW Training Range?**

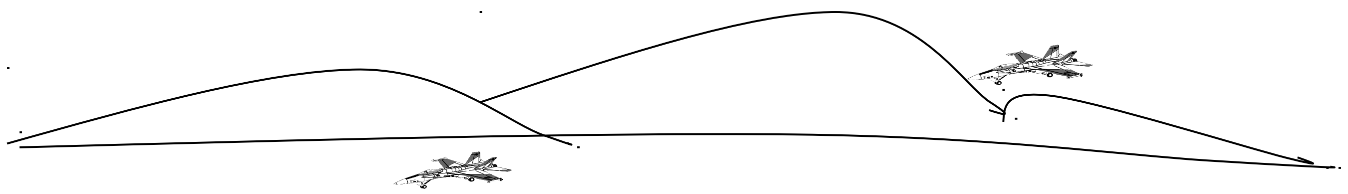
SHOWING THAT THE APPROACH CAN BE IMPLEMENTED

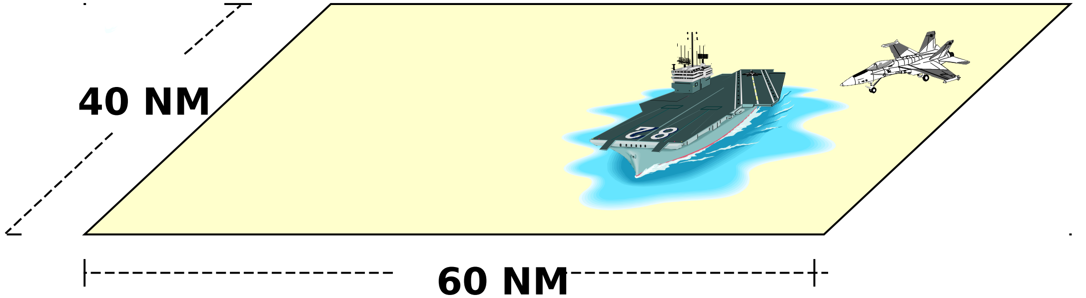
MODELING ORGANIC MINE COUNTERMEASURE OPERATIONS

MINEHUNTING OPERATION



CARRIER STRIKE OPERATION





IMPLEMENTING THE APPROACH

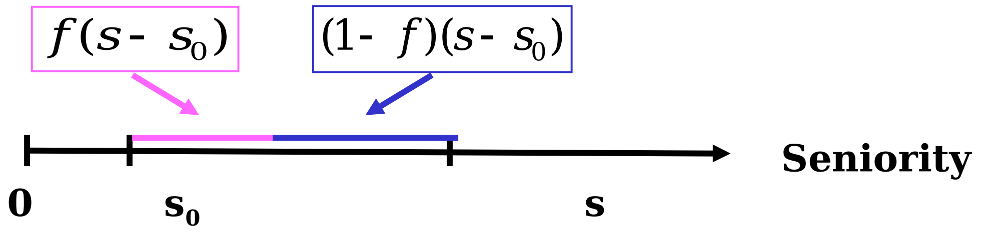
- **OPERATIONAL EFFECTIVENESS IS MEASURED BY PROBABILITY THAT CARRIER DOESN'T HIT A MINE**
- **MODEL INPUT IS THE PROBABILITY THAT POST-MISSION ANALYST CORRECTLY IDENTIFIES MINE**
- **INFRASTRUCTURE ACTIVITIES CAPTURED**
  - **Realistic Training of Post Mission Analysts**
  - **Quality of Life Affecting their Retention**
- **PARAMETERS CHARACTERIZING THE ACTIVITIES**
  - **Frequency of Realistic Training Opportunities**
  - **Retention Probability**

MODELING INDIVIDUAL PROFICIENCY

- **PROFICIENCY CHANGES DUE TO THE INTERPLAY BETWEEN LEARNING AND FORGETTING**
  - **When the Operator is Exercising his Skills, Proficiency Increases as a Result of Learning**
  - **When the Operator is not Exercising his Skills, Proficiency Decreases as a Result of Forgetting**

- **WE ASSUME THAT THE RATE OF INCREASE IS**
  - **Proportional to Current Level of Proficiency**
  - **Inverse Proportional to Length of Time the Operator Employed Skills since Last**

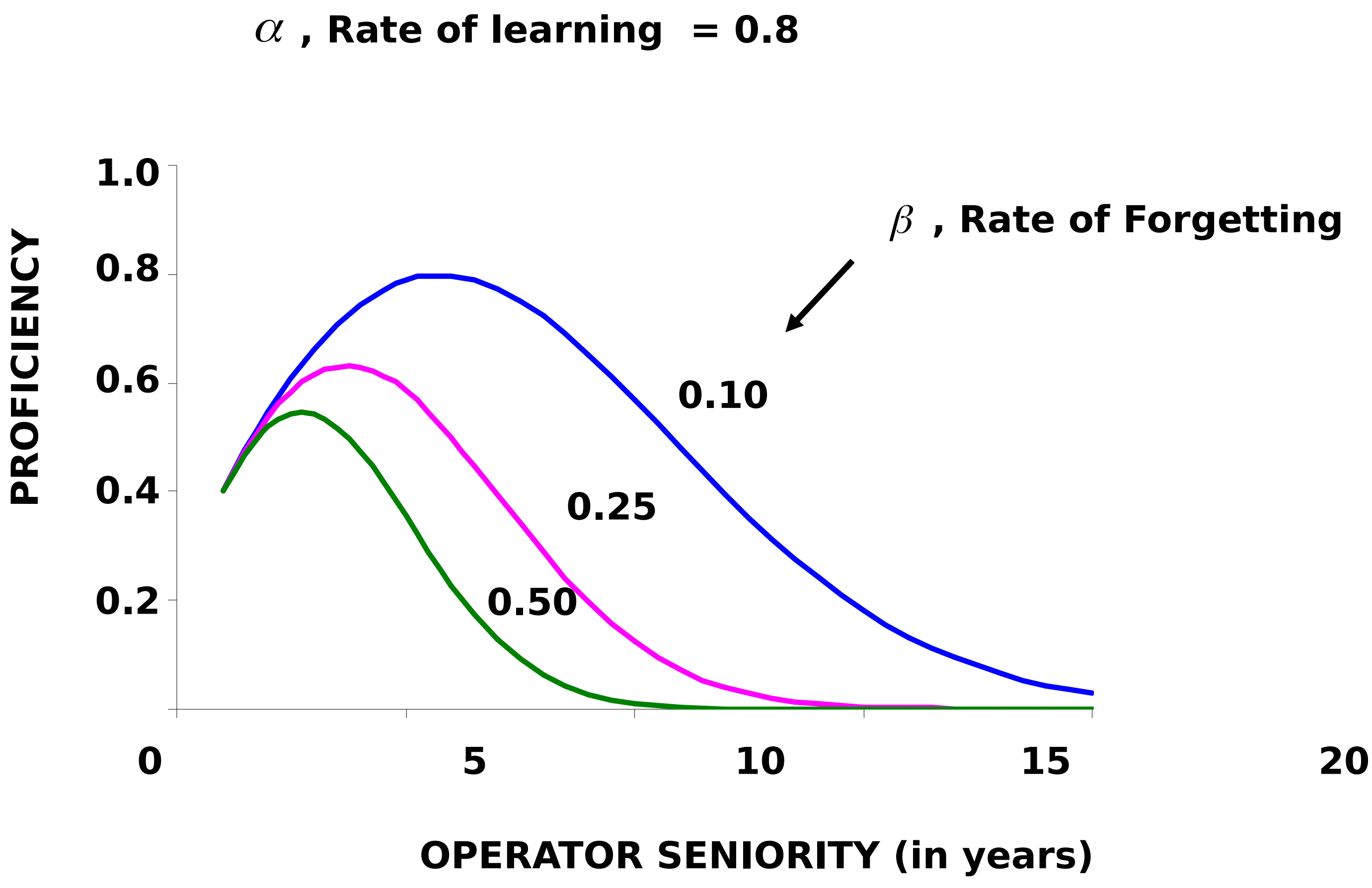
ILLUSTRATIVE SOLUTION



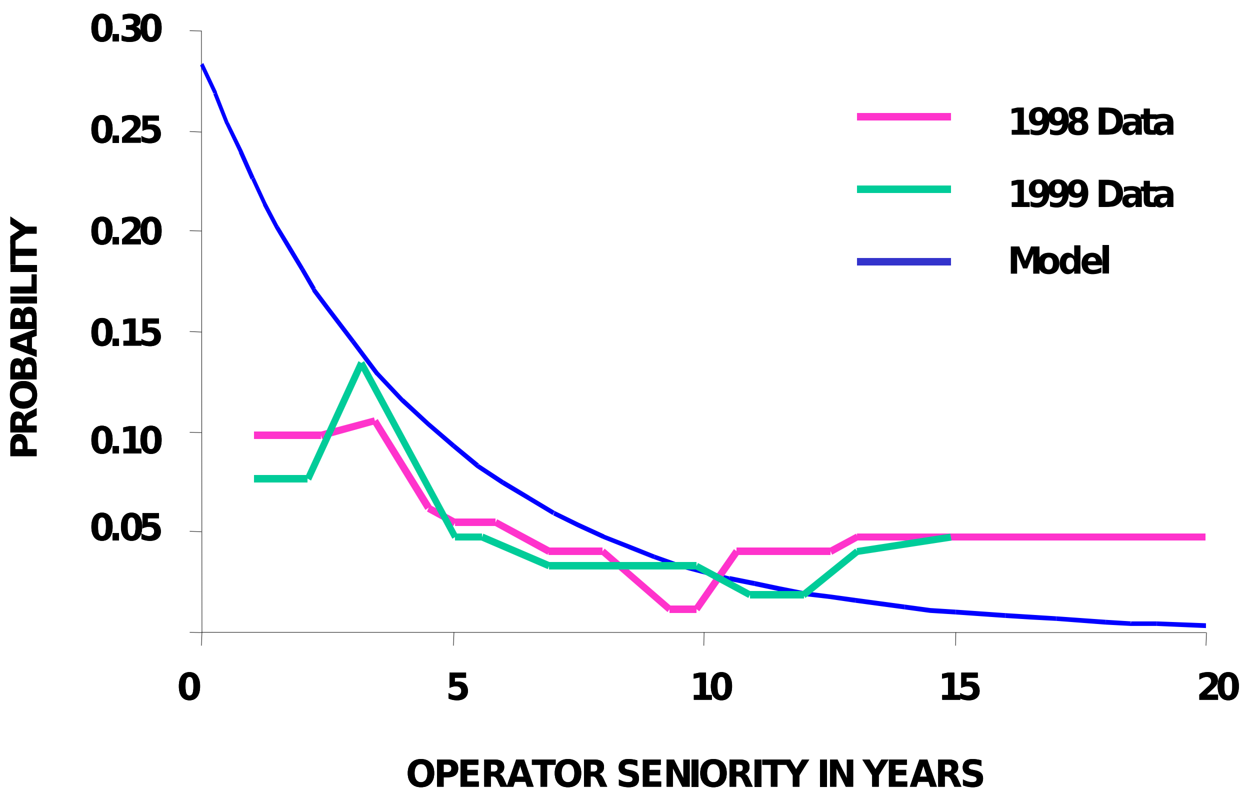
$$\frac{d\phi}{ds}=\frac{\alpha f\phi(s)}{s_0+(s-s_0)f}-\beta(1-f)(s-s_0)(1-f)\phi(s)$$

$$\boxed{\phi(s)=\phi(s_0)\left(1+\frac{s-s_0}{s_0}f\right)^{\alpha}e^{-\frac{1}{2}\beta(1-f)^2(s-s_0)^2}}$$

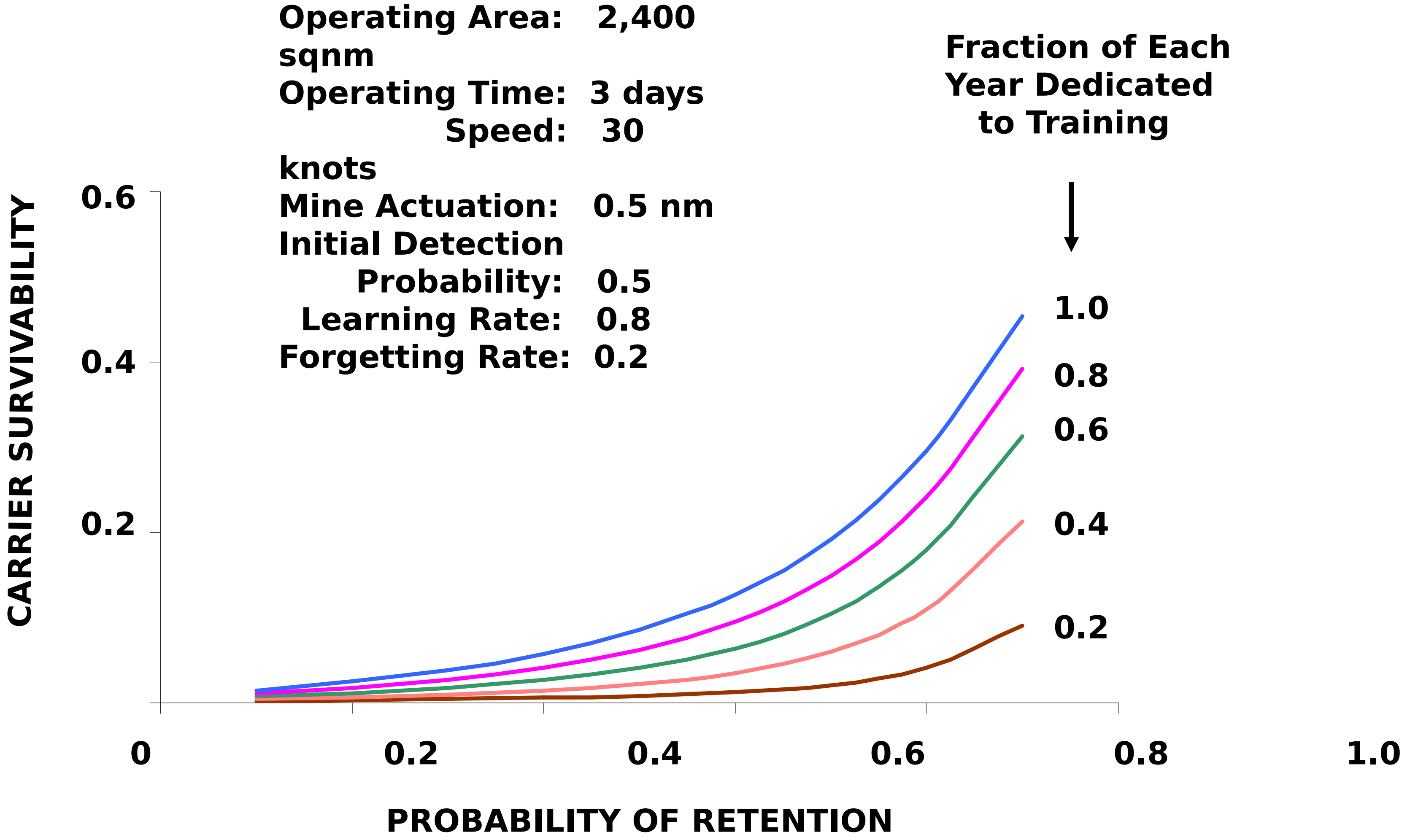
EFFECT OF OPERATOR SENIORITY



THE SENIORITY DISTRIBUTION



OPERATIONAL EFFECTIVENESS



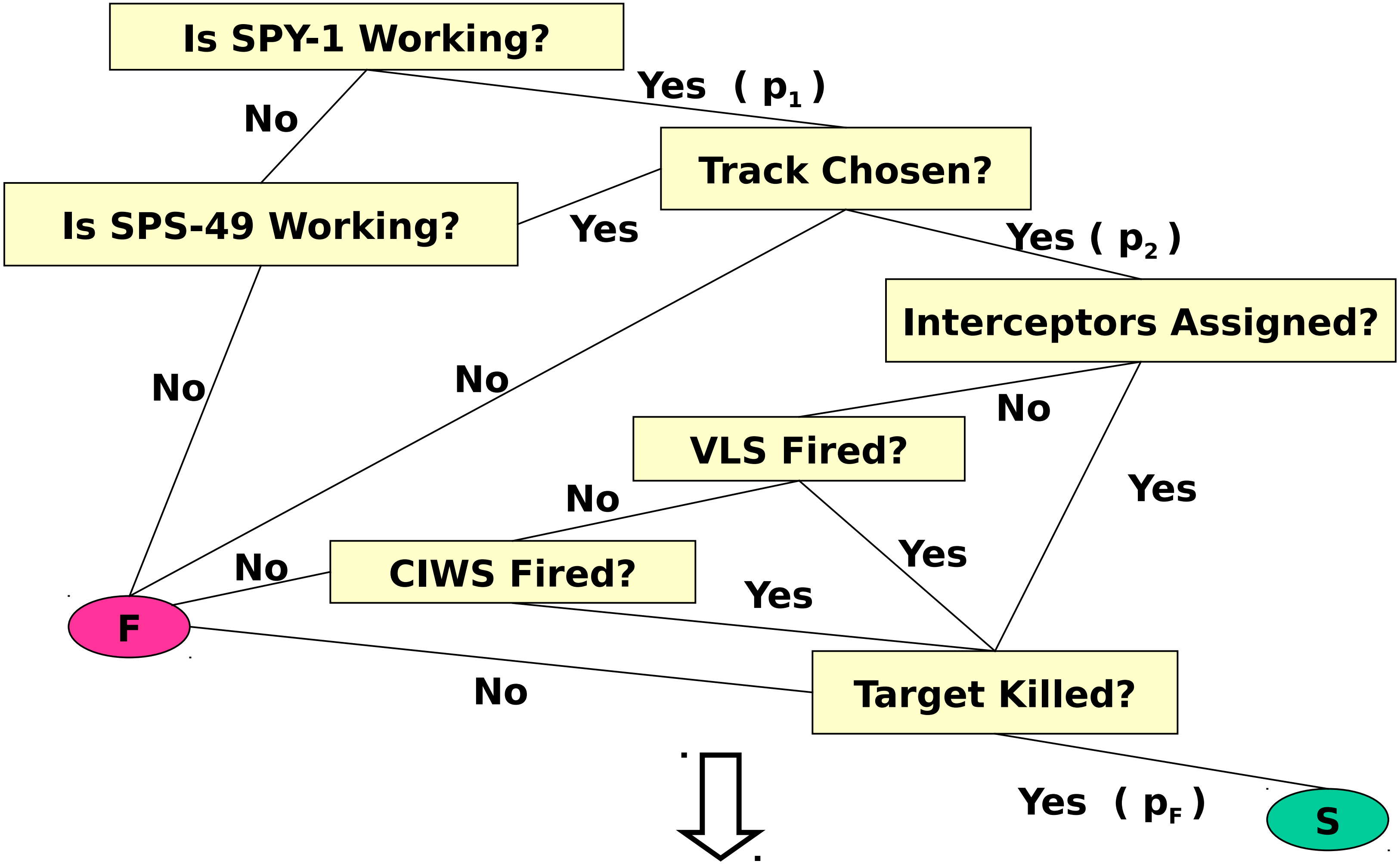
SHOWING THAT THE APPROACH CAN BE IMPLEMENTED

HOW MANY SAILORS TO MAN A SURFACE COMBATANT?

IMPLEMENTING THE APPROACH

- **OPERATIONAL EFFECTIVENESS IS MEASURED BY PROBABILITY OF SUCCESS IN PERFORMING AAW**
- **MODEL INPUTS ARE THE PROBABILITIES THAT SAILORS SUCCESFULLY COMPLETE FUNCTIONS**
- **THESE INPUTS ARE DETERMINED BY AT LEAST THE FOLLOWING INFRASTRUCTURE ACTIVITIES**
  - **Realistic Training of Each Sailor**
  - **Quality of Life Affecting his Retention**
  - **Training of Ship's Crew**
- **THESE ACTIVITIES WILL BE DESCRIBED BY**
  - **Frequency of Realistic Training Opportunities**
  - **Retention Probability**
  - **Crew Cohesion and Leadership Quality**

FUNCTIONAL STRUCTURE FOR AAW



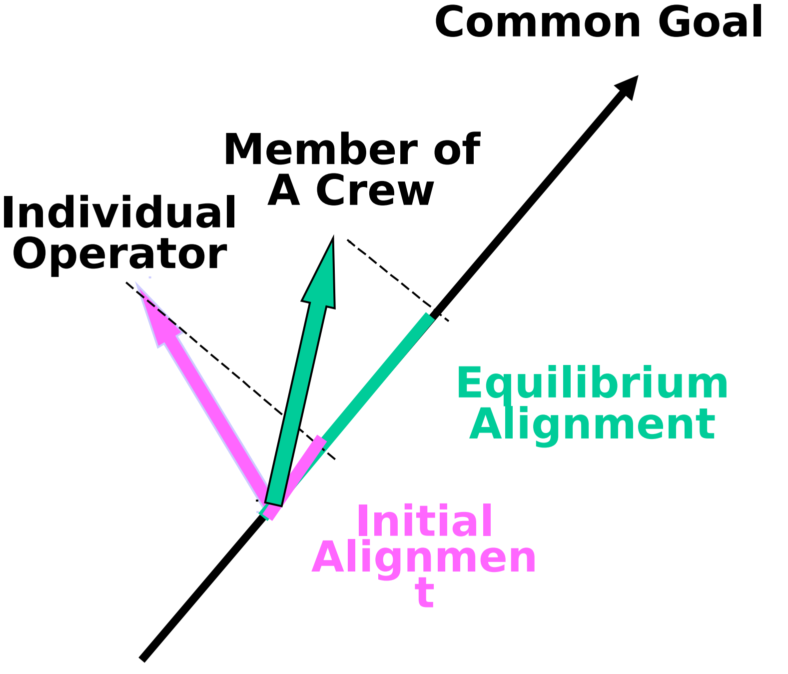
Pr (Mission Success) = μ (p_1, p_2, ……, p_{F-1}, p_F)

THE HUMAN FACTOR

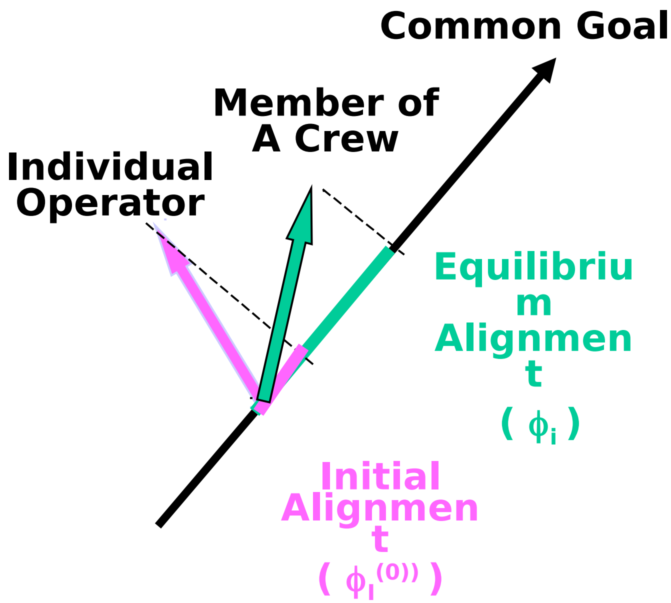
- **THERE IS NO ALLOWANCE HERE FOR HUMAN PERFORMANCE THAT IS SHORT OF PERFECT**
- **IN REALITY, HUMAN PERFORMANCE WOULD DEGRADE ALL ENGINEERING VALUES $p_i^{(eng)}$**
- **WE SHALL THEREFORE REPLACE EACH $p_i^{(eng)}$ BY $H_i \cdot p_i^{(eng)}$ WHERE THE FACTOR H_i CAPTURES**
  - **Reduction due to Individual Proficiency as a Function of Operator Seniority and Training**
  - **Enhancement of that Proficiency Induced by Crew Cohesion and Command Leadership**
  - **Reductions Induced by Excessive Time on Watch as Function of Ship’s Company**

MODELING CREW ENHANCEMENT

- **CREW IS GENERALLY MORE PROFICIENT THAN TOTALITY OF ITS MEMBERS BECAUSE**
  - **Need to Contribute to the Common Goal Induces an Organizing Tendency that Makes Each Crew Member More Proficient (Cohesion)**
  - **Leadership Reduces the Disorganizing Tendencies Generated by Individuality of its Members**
- **THE CREW REACHES ITS FULL POTENTIAL WHEN THESE TWO FORCES ARE BALANCED**



MODELING CREW ENHANCEMENT



g **Order Parameter**

h **Disorder Parameter**

$(1-\phi_i)$ **Misalignment**

B **Intensity of the Organizing Force**

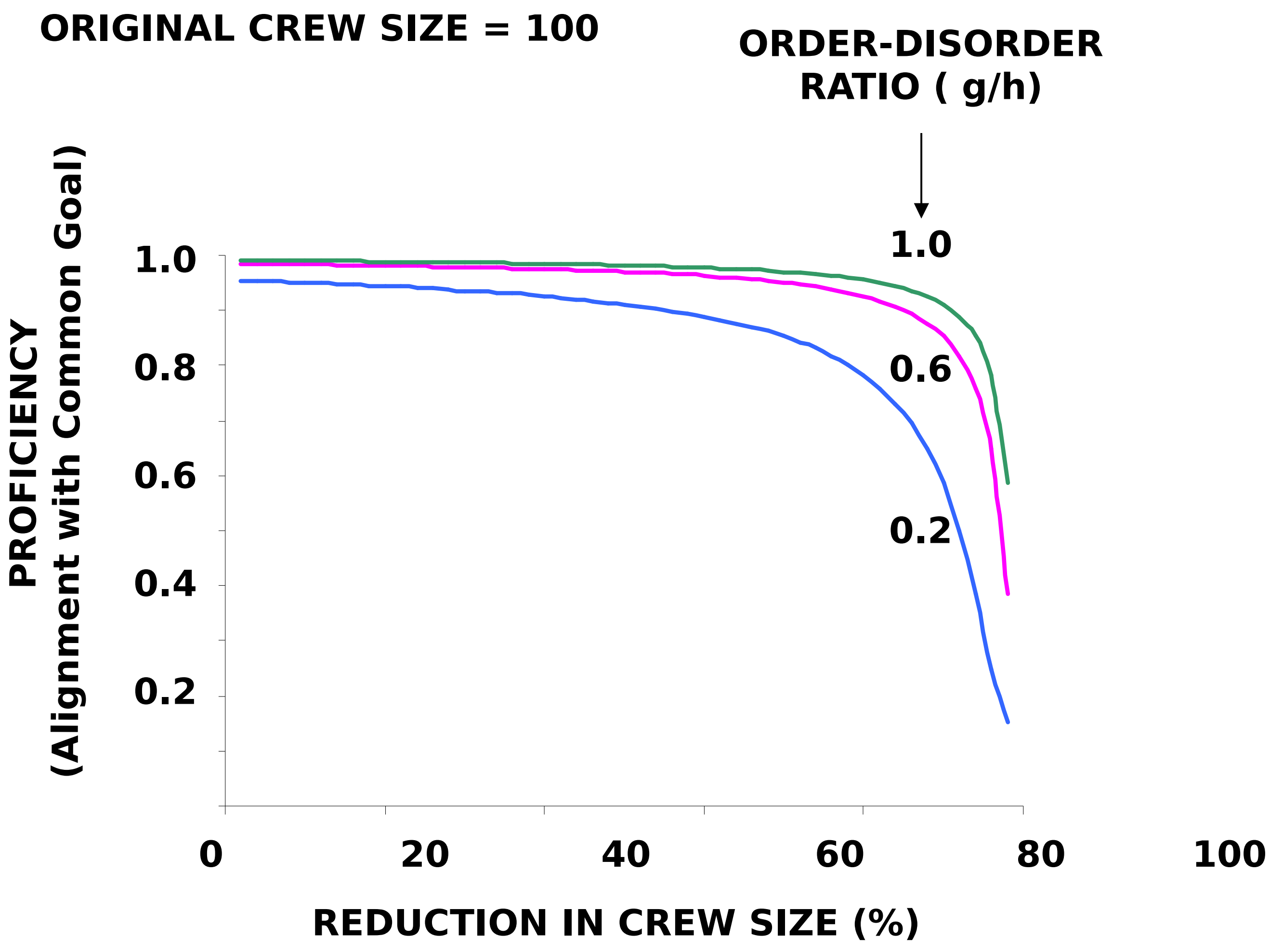
Organizing Force $= gB(1-\phi_i)$

Disorganizing Force $= h(\phi_i - \phi_i^{(0)})$

$$gB(1-\phi_i) = h(\phi_i - \phi_i^{(0)})$$

$$B = \sum_{i=1}^{F} \phi_i$$

DIMINISHING CREW SIZE



THE EFFECTS OF WATCH-STANDING

- **PERFORMANCE AT A WATCH STATION DEPENDS ON NATURE OF WATCH-STANDING OPERATION**
- **IF STATION IS MANNED IN SHIFTS, PROFICIENCY DROPS EXPONENTIALY WITH TIME ON STATION**
  - **Time on Station Decreases in Direct Proportion With Number of People Assigned to Function**
  - **The Exponent Increased by Adverse Conditions Prevailing at the Watch Station, such as Noise, Heat, Traffic, and General Disorder in the Area**
- **IF MANNED UPON REQUEST, QUALITY OF SERVICE DEPENDS UPON NUMBER OF PEOPLE ON STATION**
  - **Likelihood of a Response Increases, but**
  - **Proficiency of each Respondent Decreases**

MEASURE OF PERFORMANCE

- **FOR EACH DISTRIBUTION $\{n_i\}_{i=1 \dots F}$ OF PEOPLE OVER FUNCTIONS EVALUATE:**

$$\Pr(\text{Mission Success} \mid \{n_i\}) = \mu\,[\,H_1(g/h, n_1, \lambda_1)\, p_1^{eng},\; H_2(g/h, n_2, \lambda_2)\, p_2^{eng},\; \ldots\ldots,\; H_F(g/h, n_F, \lambda_F)\, p_F^{eng} ; F\,]$$

- **MAXIMIZE THIS CONDITIONAL PROBABILITY OVER ALL DISTRIBUTIONS $\{n_i\}_{i=1 \dots F}$ FOR GIVEN VALUES *F***

- **MEASURE PERFORMANCE BY THE RESULTING OPTIMAL PROBABILITY AS A FUNCTION OF *F***

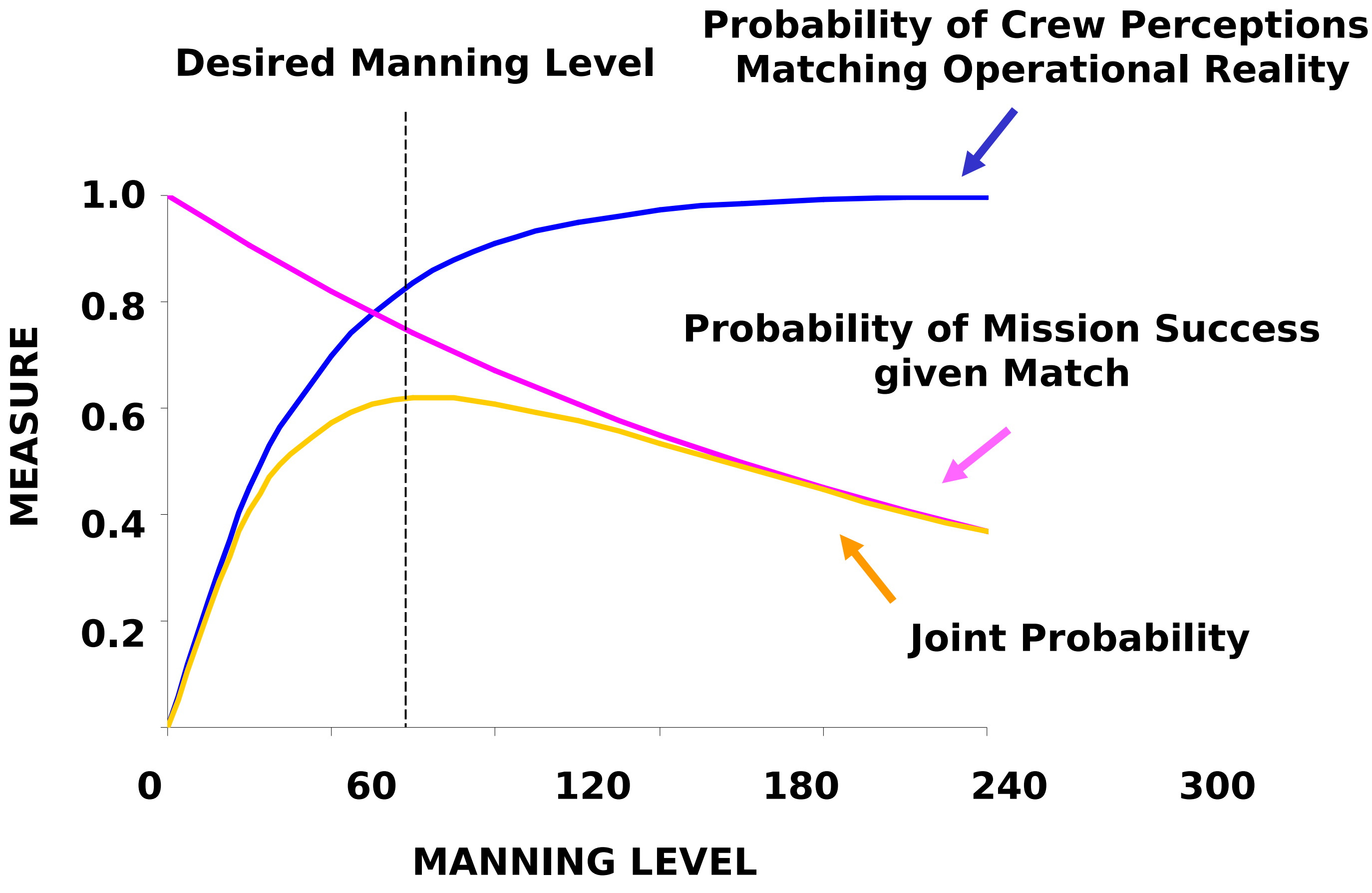
RISK OF AUTOMATION

- **SINCE MACHINES FUNCTION BETTER THAN MEN**
  - **Human Factor H is Generally Less than One**
  - **Replacing Humans with Machines would Raise Proficiency from $H.p^{eng}$ to p^{eng}**
  - **One Might Want to Automate All Functions**
- **HOWEVER, IF THE SITUATIONAL ASSUMPTIONS MADE BY THE CREATOR WERE NOT ACCURATE,**
  - **What Machines Do will not Necessarily Match with the Prevailing Situation and their Action Might Prove to be Counterproductive**
  - **Unlike Humans, Machines will not be Able to Correct the Situation in Time to Matter**
- **THEREFORE, AUTOMATING ALL SHIP FUNCTIONS WOULD REDUCE OVERALL PERFORMANCE**

SEEKING PROPER CREW SIZE

- **AS SHOWN ABOVE, AUTOMATION TENDS TO**
  - **Increase Ship Performance by Replacing Men with Faster, More Accurate Machines, though Crew Behavior may Mitigate that Somewhat**
  - **Decrease Ship Flexibility by Replacing Men with Less Adaptable, Less Robust Machines**
- **THUS, REDUCING MANNING BY AUTOMATING MORE FUNCTIONS SHIFTS BALANCE BETWEEN**
  - **Ship's Operational Performance as Measured by Probability of Mission Success Optimized over $\{n_i\}_{i=1\ldots F}$ for a Specified Manning Level *F***
  - **Ship's Operational Flexibility as Measured by Probability of a Match Between the Crew's Perceptions and Operational Reality Given *F***
- **SEEK THE MANNING LEVEL *F* THAT BALANCES MISSION EFFECTIVENESS WITH FLEXIBILITY**

BALANCING PROCESS



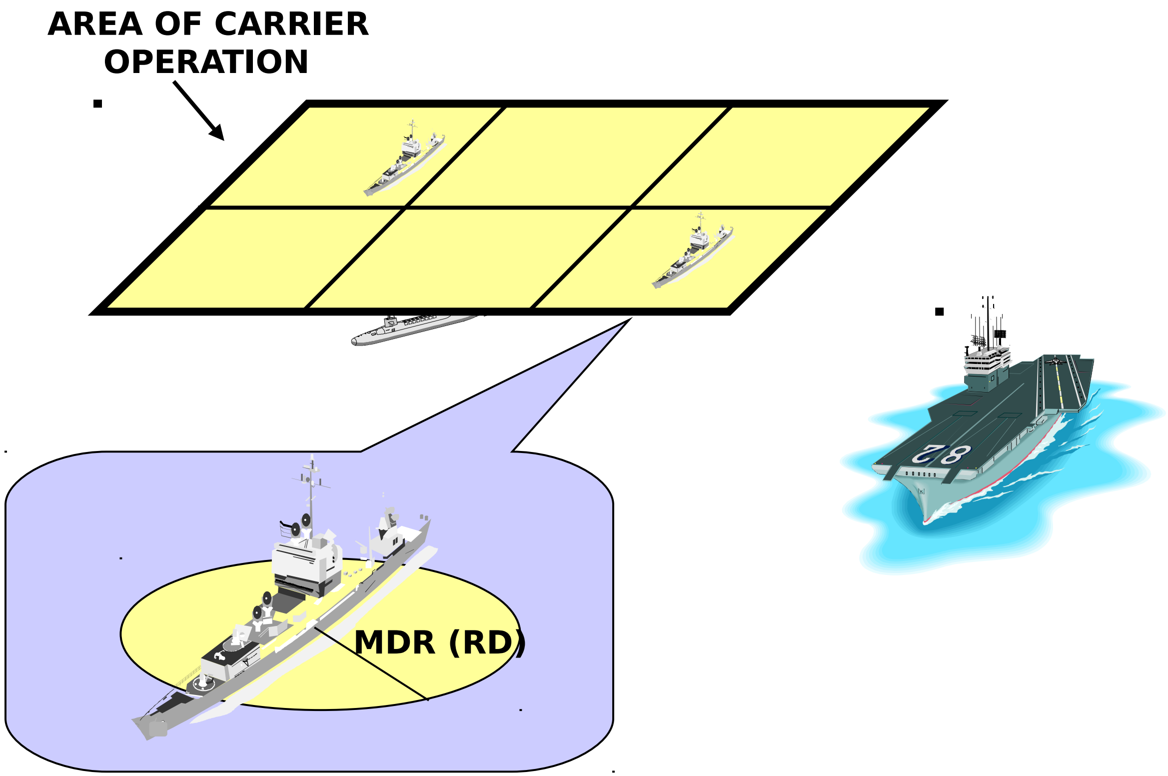
SHOWING THAT THE APPROACH CAN AID DECISION MAKERS

SHOULD THE NAVY BUILD A SHALLOW WATER ASW TRAINING RANGE?

THE TRAINING RANGE ISSUE

- **THERE ARE THREE KEY ISSUES THE NAVY MUST SETTLE BEFORE A DECISION COULD BE MADE**
  - **Will Ranges Conform to Environmental Regulations Prevailing in the Area?**
  - **Will Sonar Operator Schedules Allow Full Exploitation of these Facilities?**
  - **Is Investment in these Ranges Justified by the Increased Operational Capability?**
- **TO ANSWER THE LAST QUESTION, WE CONNECT CAPABILITY TO TRAINING IN PRECURSOR ASW**

PRECURSOR ASW OPERATIONS



IMPLEMENTING THE APPROACH

- **OPERATIONAL EFFECTIVENESS IS MEASURED BY PROBABILITY THAT SUBMARINE FAILS TO HIT CV**
- **MODEL INPUT IS RECOGNITION DIFFERENTIAL**
- **INFRASTRUCTURE ACTIVITIES CAPTURED**
  - **Initial Training at ASW Operator School**
  - **Subsequent Training in Shallow Water ASW**
- **PARAMETERS CHARACTERIZING THE ACTIVITIES**
  - **Recognition Differential at Graduation**
  - **Frequency of Realistic Training Opportunities**

THE TRADE-OFF PROCESS